

Bridging the Health Care Gaps Using Labike as an Innovative Diagnostic Tool Among the Underprivileged Rural & Urban Populations: Experience from Kashmir

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Abstract

Background: Access to diagnostic facilities is severely compromised for socio-economically marginalized populations due to barriers of distance, high transportation costs and lost wages, thus undermining efforts towards Universal Health Coverage (UHC). The ICMR pre-validated Labike-a laboratory mounted on a motor cycle was developed to ensure accessible lab diagnostic services at the door step. **Objectives** 1. To assess the prospects of acceptability and scalability of the ICMR pre-validated Labike by highlighting the experiences with regard to its technical and operational feasibility at the door step 2. To assess the acceptability and satisfaction with this door step lab service among the screened respondents. **Material and Methods:** This was a part of larger implementation research study (with a pre-intervention, Intervention & Post-intervention stage) conducted over two years in selected underprivileged rural and urban areas of Kashmir as a part of multi-centric ICMR Task Force Project. The study utilized a purposive sampling strategy to select underprivileged rural and urban populations. In the present study, lab services were provided at the doorstep during a baseline screening of the eligible population (aged 10 years & above) for various lab parameters (Hb, ESR, LFT, KFT, Lipid Profile, Blood Sugar, Routine urine etc.) A total of 1212 eligible beneficiaries, who consented for lab screening were tested at their door steps. Community acceptability was assessed by interviewing a sub-set of 573 beneficiaries using a self-designed questionnaire focusing on convenience, cost, privacy, and satisfaction. **Results:** The Labike demonstrated overwhelmingly high acceptance as 99% of beneficiaries recommended the continuity of the Labike service while as, 74.3% were ready to pay a nominal charge. High satisfaction was recorded across all parameters, including accessibility, suitability of working hours, and reduced travel time (98.4% satisfied/very satisfied). The Labike proved to be a robust and reliable diagnostic platform, with results showing high coherence when cross-checked with the tertiary care lab. The compact design facilitated access to difficult remote terrains. However, Key challenges included environmental vulnerability (equipment malfunction and battery drain in extreme cold), ergonomic constraints (single-technician design), reliance on expensive proprietary consumables (cuvettes), and lack of built-in bio-medical waste segregation/disposal system. Interrupted internet connectivity in the study areas prevented real-time data synchronization. **Conclusion:** The Labike is a highly acceptable, effective, and potentially scalable tool for revolutionizing diagnostic outreach and strengthening primary health care in resource-limited settings. However, for successful large-scale rollout, certain modifications to address the technical vulnerabilities of cold weather, integrating non-proprietary consumables for supply chain resilience and establishing built-in policy-driven protocols for bio-medical waste management need to be considered.

Keywords: Accessibility, Availability, Affordability, Diagnostic, Labike.

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INTRODUCTION

Availability, accessibility and affordability constitute the important attributes of quality healthcare and are the fundamental pillars of any health care system. On the contrary, health care gaps pose the major challenges in the process of achieving universal health coverage-an important goal for almost every nation in the world.^[1-3] Data from NFHS 5 and other sources, reflect prominent gaps both in the health care infrastructure as well as health status of the population especially among the underprivileged and remote pockets of the country.^[4-6] Covid-19 pandemic has further exposed the vulnerability of the fragile health care systems especially in the remote, difficult to reach and socio-economically backward populations and has hence,

underscored the need of an efficient patient care mechanism rooted in sound mobile health care solutions. Keeping in view the adversities of the past and in line with the country's vision to achieve the universal health care goals, a lot of innovative

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measures have been taken in the recent times both in private and public sector to bridge the health care gaps by enhancing the patient care with a robust diagnostic management system. Labike -a lab mounted on bike is one such state-of-art, lab diagnostic tools developed by Accuster Technologies Pvt. Ltd and pre-validated by ICMR New Delhi,^[7] -one of the prestigious research organizations of the country.

As a part of ICMR sponsored multi-centric Task Force Project titled, “Task force study for evaluation of community level acceptability, scalability and linkage within health system of ICMR pre-validated Labike technologies for screening & diagnosis in rural and urban population—an implementation research”, the Labike was used for door step testing in various selected sites across different regions of the country with an objective to assess its implementational prospects. As a part of this multi-centric ICMR study, the current paper attempts to highlight the collective implementational prospects of Labike by exploring its structural frame work, operational work flow, cost feasibility, degree of acceptability together with all the operational challenges encountered in the field during its operationalization in Kashmir, one of the study sites.

Objectives: The current study attempted to:

1. Assess the prospects of acceptability and scalability of the ICMR pre-validated Labike by highlighting the experiences with regard to its technical and operational feasibility at the door step.
2. To assess the acceptability and satisfaction with this door step lab service among the screened respondents.

MATERIALS AND METHODS

The multi-centric task force study titled, “Task force study for evaluation of community level acceptability, scalability and linkage within health system of ICMR pre-validated Labike technologies for screening & diagnosis in rural and urban population— an implementation research” was conducted in six sites across India namely Kashmir(J&K), Guwahati (Assam), Bhopal (M.P), Muzaffarpur (Bihar), Varanasi (U.P) & Chennai (Tamil Nadu). For Kashmir Site, the study was undertaken by the Department of Community Medicine, SKIMS, Soura, Srinagar.

Study design: The current study is a part of the baseline pre-intervention phase of the main task force study.

Study area: The study was conducted in selected underprivileged rural and urban population of Ganderbal and Srinagar districts. For this purpose, district Srinagar represented the urban component while as district Ganderbal represented the rural component.

Study duration: This phase of the task force study was carried out over a period of one year.

Study population: Selected underprivileged rural and urban population belonging to District Ganderbal and District Srinagar.

Study participants: The main task force study was conducted in a pre-designed sample of 5000 participants/study site as worked out by ICMR based on the prevalence of non- communicable diseases,^[8] in which,

besides a base line survey of the entire sample population, blood screening was to be done for respondents aged 10 years and above only after seeking the requisite consent. However, a total of only 1212 respondents consented for the lab tests which included blood screening for various parameters like LFT, KFT, Lipid Profile, Blood Sugar (Random/Fasting), Hb, ESR, Routine urine, Urinary protein, on demand Rheumatoid factor, CRP, Triple serology & Blood grouping etc. during the first year (pre-intervention phase).

Inclusion criteria: All the respondents of the selected households aged 10 years and above for which the respondent/head of the household provided the consent for blood testing.

Exclusion criteria:

- Respondents below the age of 10 years.
- Eligible respondents for which the consent for sampling was not provided.

In the current study, a sub-sample (573) of these 1212 respondents undergoing blood screening, acceptability and level of satisfaction with the door step Labike service was assessed by using a self-designed questionnaire focusing on various aspects of satisfaction among the respondents.

Data Analysis

The collected data was entered in MS Excel and subsequently analysis was carried out with the help of IBM SPSS Statistics Software version 21.

RESULTS/OBSERVATIONS

Labike:Structural makeup and operational framework
ICMR pre-validated Accuster Labike is a fully equipped, eco-friendly, state-of-art mobile diagnostic laboratory tailor-made for resource limited remote environments and is mounted on a motorcycle which performs on-site testing and health profiling.

1. The structural make up and operational mechanisms of the Labike is comprised of:

a. A 150cc Pulser bike.

b. Mobile Diagnostic Setup:

This is the core part of the Lab and is comprised of following sub-parts:

• **Semi-Automated Biochemistry Analyzer and Potable Centrifuge:**

These essential diagnostic tools are mounted in convertible compact compartments for field use and are meant for performing biochemistry tests such as liver function, lipid profile, blood glucose, KFT, urine analysis etc.

• **Microscope:**

A portable, rechargeable microscope used in performing microscopic examinations of urine and blood samples.

• **Battery-Powered Equipment:**

To ensure the functionality of the LABIKE in areas devoid of electricity, the setup is powered by rechargeable batteries chargeable from an external power source as well as solar board installed in the setup.

c. **Side mounted Containers:**

Two side mounted chambers equipped with cold chain containers are meant to carry the necessary lab consumables such as pipettes, syringes, gloves, reagents, tubes etc. for on-site testing.

d. Integrated Tools:

Apart from the above apparatus, the other necessary tools provided with the Labike contain:

i. Anthropometric Device: This contains an automatic device for automatic BMI calculation.

ii. Blood Pressure Apparatus: A portable device for measuring the Blood Pressure.

iii. Canopy Tent: A foldable tent for housing the whole setup in field and for providing the protection from the unfavourable climatic conditions.

iv. Foldable chairs: A pair of foldable chairs for the technicians performing the lab tests.

2. Technical and Operational feasibility of Labike: Experiences from field

The ground experience of utilizing the Labike services for the door step diagnostic lab testing has yielded few deep and enriching insights both from technical and operational point of view. From technical point of view, the compact design of the Labike makes it manoeuvrable for difficult terrains where the large vehicles would otherwise struggle to reach and, thus, it, broadens the scope of health care services in such settings. By bringing the diagnostic lab services at the door step of otherwise remote, inaccessible and vulnerable populations, it not only enhances accessibility of these services in such settings but, also ensures their affordability by eliminating the expenditure incurred and time lost in travel. Further, the enabling feature of the Labike to collect, process and analyse the blood samples in the same location apart from ensuring the comprehensive real-time diagnostics, also minimizes time lag as the test reports are delivered the same day. Besides the bio-chemistry tests, the add on integrated tools provided with the Labike in the form of Portable automatic BMI device and blood pressure apparatus helps in timely monitoring of BMI and blood pressure and, hence, helps in detecting the potential risks like obesity and other cardio-vascular ailments and risk factors. Moreover, the provision of GPRS feature in the Labike, facilitates a real-time transmission of the data from the very field site. The innovative tool enables the collection, storage, analysis and utilization of health-related data to help in planning, management, evaluation and decision-making in health sector. On operational front, the Labike functions independently of any direct external power source drawing energy from inbuilt portable rechargeable batteries as well as the solar panel installed in it. This ensures hassle free diagnostic lab work in areas devoid of electricity or receiving erratic power supply. Additionally, the compact design of the Labike coupled with its multi-functional capabilities allows the performing of wide range of diagnostic tests by a single technician. All these features reduce the operational costs of the Lab and hence, make it eco-friendly, efficient and economical. On quality front, the Lab tests performed on the Labike are equally reliable as divulged from the cross analysis of the test reports. To cross-check the accuracy of lab tests performed on the Labike, samples were randomly sent to biochemistry lab of tertiary care hospital for quality check at regular intervals. The cross-checked test reports revealed that the results from the two labs were by and large coherent. Out of 1212 tests performed for various parameters

on the Labike, around 60 samples were cross-checked for quality. Based on the field experience, there is no denying the fact, that the Labike has numerous advantages as, it ensures the door step availability of the diagnostic services in difficult terrains at affordable prices; eliminates travel expenditure incurred in the conventional diagnostic lab testing and is also time saving. Besides, its onsite presence facilitates the community awareness and engagement by proving a cue to health. However, some of the areas amenable to improvisation were identified during the operationalization of the Labike in the field.

The diverse set of challenges faced during the course of its operationalization included technical and environmental challenges; ergonomic and operational constraints, work flow limitations and waste management issues etc. The field experience showed that the diagnostic equipment malfunctions (showing erroneous results) under extreme cold weather conditions due to reagent instability. Moreover, because of the compact design, the centrifuge cannot handle the large vacutainers which compromises its ability to process larger samples with added anti-coagulants. Apart from this, the centrifuge's high-speed operation requires frequent recalibration which is highly labour intensive. Further, the solar powered battery equipped in the analyser as an alternative source to major batteries, drains quickly in sub-zero temperatures and, hence, can't be relied upon for long durations in case the main batteries are discharged. Further, the limitation of using only customised and expensive Accuser based proprietary cuvettes in the semi-automatic analyser of the Labike, hampers the work process, given their non-availability in the open market. Besides, the cuvettes being vulnerable to scratches, show distorted test results after few uses, which compromises the accuracy of the analyser. Among other challenges which limits the scope of Labike are the space limitations, safety risks and inadequate shelter. The compact design of the Labike mounted with other installations for logistic support, makes it impossible to accommodate the second technician, which makes it difficult for a single technician to simultaneously handle samples, perform tests and manage patients. Additionally, the uneven weight distribution due to mounted equipment makes it highly difficult to maintain the balance of the Labike, especially in rough terrains, which poses safety concerns to both the technician and the Labike. Apart from this, the canopy provided with the Labike for providing a makeshift/temporary sheltered workspace in the field conditions was neither heat resistant nor water proof, which not only caused a lot of discomfort to the technicians but, also, affected the efficiency of the Labike. One of the important challenges faced throughout the course of work was the issue of segregation of bio-medical waste and its disposal. In the wake of the absence of colour-coded bins and lack of any sterilization method, the improper handling of the generated waste can prove highly detrimental both for the public health as well as for the environment. Besides the above challenges, lack of internet connectivity/impaired internet connectivity (use of jammers as a security measure in some areas) was a major systemic constraint, which prevented the intended real-time data synchronization in our study site.

Labike as a future diagnostic tool

In line with the second objective of this study and to forecast the prospects of Labike as a future diagnostic tool, a subset of the

beneficiaries was interviewed using a self-designed pre-tested questionnaire based on socio-demographic characteristics and questions on diverse themes such as preference for Government and Private labs, average distance travelled to lab, expenditure incurred on

transportation charges, quality of test reports, privacy, time lags, test coverage, comfortability and economic viability etc. in order to know their perspective based on their first-hand experience of having availed the Labike facilities for their base line blood screening during the pre-intervention phase of the study.

Table 1: Socio-Demographic Profile of the Respondents. N-573

Socio-demographic characteristics	Frequency (N)	Percent (%)
Age(Years)		
10-19	111	19.4
20-39	248	43.4
40-59	94	16.4
60 and older	120	20.9
Gender		
Male	153	26.7
Female	420	73.3
Educational status		
Illiterate	318	55.5
Upto High School	243	42.4
Higher Secondary & above	12	2.1
Occupational status		
Homemaker/student/Unemployed	553	96.5
Labour/Self-employed /Pvt Job	15	2.6
Govt. Employee/ SMC Workers	5	.9
Residence		
Rural	282	49.2
Urban	291	50.8
Total	573	100.0

[Table 1] depicts the socio-demographic profile of the respondents interviewed. The age distribution of the respondents reveals that 111 (19.4%) of the respondents belonged to the age group of 10-19 years, 248 (43.4%) belonged to the age group of 20-39 years, 94 (16.4%) belonged to age group of 40-59 years while as 120 (20.9%) belonged to the age group of ≥60 years. With regard to the gender, a female preponderance was found with 420 (73.3%) females as against 153 (26.7%) males. Residential status of the respondents was almost equipoised with 282 (49.2%) as

rural and 291 (50.8%) as urban dwellers. Educational profile of the respondents revealed that 318 (55.5%) were illiterate as against 243 (42.4%) who had studied upto high school and 12(2.1%), whose educational qualification was Higher secondary and above. Further, occupational status of the respondents revealed that majority of the respondents 553 (96.5%) belonged to the category of unemployed/homemakers/students as against 15(2.6%), who belonged to the category of Labour /Self-employed /Pvt Job and 5(0.9%) who were Govt. Employee/ SMC workers.

Table 2: Distribution of study participants by past experiences regarding utilization of lab services. N-573

Lab Testing Facility used	Frequency (N)	Percent (%)
Government facility	285	49.7
Private facility	222	38.7
Both Government & Private facility	66	11.5
Total	573	100.0
Distance to travel for lab testing		
< 5Km	294	51.3
5-9 Km	15	2.6
10-14 Km	249	43.4
>15Km	15	2.6
Total	573	100.0
Mode of Transport used		
On foot	60	10.5
Public Transport	474	82.7
Private Transport	39	6.8
Total	573	100.0
Amount spent (in Rs)		
Zero	90	15.7
<100	120	20.9
100-499	342	59.7
500-1000	21	3.7
Total	573	100.0

[Table 2] depicts the distribution of study participants by their past experiences regarding the use of lab services. 285(49.7%) of the respondents had used Government lab facilities, 222(38.7%) used private and 66(11.5%) used both government and private lab facilities. 294(51.3%) had travelled less than 5 km distance for lab testing, 15(2.6%) travelled 5-9 Kms, 249(43.4%) travelled 10-14 kms and another 15(2.6%) travelled more than 15kms to reach the lab

facility. 474(82.7%) had used public transport, 39(6.8%) used private transport while 60(10.5%) covered the distance to the lab facility on foot. The amount spent for the lab testing by the individuals was Rs. 100-499 in 342(59.7%) respondents, less than Rs 100 in 120(20.9%), Rs. 500-1000 in 21(3.7%) respondents while no expenditures were incurred in 90 (15.7%) respondents.

Table 3: Distribution of respondents by preference to Lab Testing Facility. N=573.

Preferred Lab Testing Facility	Frequency	Percent
Government facility	285	49.7
Private facility	222	38.7
Government & Private facility	66	11.5
Total	573	100.0

[Table 3] depicts that 285 (49.7%) respondents preferred government lab facilities while as 222(38.7%) preferred private labs and another 66 (11.5%) used both government as

well as private lab facilities.

Table 4: Distribution of study participants using Labike services with regard to various parameters of satisfaction. N=573.

Parameters of satisfaction	Frequency (N)	Percent (%)
Accessibility to the services		
Excellent	3	.5
Very good	519	90.6
Good	42	7.3
Average	6	1.0
Poor	3	.5
Total	573	100.0
Suitability of working hours		
Suitable	564	98.4
Not Suitable	9	1.6
Total	573	100.0
Hampered your routine schedule		
No	555	96.9
Yes	18	3.1
Total	573	100.0
Satisfaction with the reduction in travel time due to home-based diagnostic services		
Very satisfied	381	66.5
Satisfied	183	31.9
Neutral	6	1.0
Poor	3	.5
Total	573	100.0
Rating for privacy and transparency		
Excellent	3	.5
Very good	42	7.3
Good	519	90.6
Average	6	1.0
Poor	3	.5
Total	573	100.0
Convenience of Labike services		
Highly Convenient	441	77.0
Convenient	129	22.5
Inconvenient	3	.5
Total	573	100.0
Quality of services received		
Excellent	3	.5
Very good	9	1.6
Good	546	95.3
Average	6	1.0
Poor	9	1.6
Total	573	100.0
Readiness to pay nominal charges for continuation of service		
	Frequency	Percent
Yes	426	74.3
No	147	25.7
Total	573	100.0

Recommends Continuity of Labike service in future		
No	6	1.0
Yes	567	99.0
Total	573	100.0

[Table 4] depicts the distribution of study participants by various parameters of satisfaction regarding the Labike services availed. With regard to accessibility 519(90.6%) participants graded the services as very good, 42(7.3%) as good, 6(1%) as average, 3(0.5%) as excellent and an equal number 3(0.5%) as poor. 564(98.4%) respondents considered the working hours of the Labike services suitable while only 9(1.6%) found it unsuitable. 555(96.9%) respondents stated that the services did not hamper their routine schedule while as only 18(3.1%) stated that the services hampered their routine schedule. 381(66.5%) respondents were very satisfied with the reduction in travel time due to home based diagnostic services, 183(31.9%) were satisfied, 6(1%) showed a neutral response while as in 3(0.5%), the

satisfaction level was poor. With regard to the rating for privacy and transparency, it was excellent in 3(0.5%), very good in 42(7.3%), good in 519(90.6%), average in 6(1%) and poor in 3(0.5%). 441(77%) respondents found the Labike services highly convenient, 129(22.55%) found it convenient and only 3(0.55) found it inconvenient. The quality of Labike services was rated as excellent by 3(0.5%) respondents, very good by 9(1.6%), good by 546(95.3%), average by 6(1%) and poor by 9(1.6%). 426(74.3%) respondents were ready to pay nominal charges for the Labike services while 147(25.7%) were not ready to pay for it. 567(99%) respondents recommended continuity of Labike services in future.

Table 5: Distribution of Study Participants by Recommendations for more Tests. N-573.

Recommend more tests in the Labike	Frequency (N)	Percent (%)
Yes	561	97.9
No	12	2.1
Type of Lab Test/Investigation recommended		
Not applicable	12	2.1
All investigations	45	8
CBC(All parameters)	89	15.8
USG/ X-RAY	33	5.8
ECHO	30	5.3
RH factor	6	1
Hormonal assay	27	4.8
Iron Profile	80	14.2
Thyroid Function Test	322	57.4
VIT D	167	29.7
HbA1c	190	33.8
Hepatitis Test	60	10.7
Allergy Test	10	1.8
Urine culture	39	6.9

[Table 5] depicts the distribution of study participants by recommendations for more tests to be incorporated in the Labike. 561(97.9%) respondents recommended inclusion of more tests in the Labike over and above the ones available in it. The recommended tests included CBC (All parameters) by 89(15.8%) respondents, USG/X-RAY by 33(5.8%), RH factor 6(1%), Hormonal essay 27(4.8%), Iron profile 80(14.2%), Thyroid Function Test 322(57.4%), Vitamin D 167(29.7%), HBAIC 190(33.8%), Hepatitis test 60(10.7%), Allergy 10(1.8%), Urine culture 39(6.9%)

DISCUSSION

The field experience of the using the Labike technology in underprivileged rural and urban areas of Kashmir clearly demonstrates its significant potential as a scalable and acceptable solution for bridging existing diagnostic and primary health care gaps. The findings beyond any doubt validate the effectiveness of this innovative tool to address the three fundamental pillars of quality health care through ensuring accessibility(By significantly reduced travel time and effort, door step Labike diagnostic services made critical testing available to populations in difficult-to-reach terrains), affordability;(By eliminating the necessity for costly and

time-consuming travel to fixed-location laboratories, the Labike drastically reduced the indirect expenditure burden on socio-economically marginalized communities) and acceptability(As reflected from positive feedback from the community evidenced by high satisfaction scores for convenience and privacy and a 99% recommendation rate for the continuity of the service, which demonstrates its high community acceptability and feasibility for long-term deployment).

As revealed from the data, the availability of the quality diagnostic facilities nearer to the people remains a matter of ultimate concern for the people as majority of the people have to travel fair good distances for availing such facilities. The trend suggests that, 51.3% of the respondents traverse a distance of <5kms; 2.6% traverse a distance of 5-10 kms; 43.4% traverse a distance of 10-14 kms and 2.6% traverse a distance of >15 kms to avail the common diagnostic facilities.

The implication of travelling to distances for availing diagnostic lab facilities compromises the readiness of the people especially the poor stratum of the population towards diagnostic lab tests as,^[9] it is not only time consuming but,

imposes an additional expenditure on them on account of transport charges besides, snatching their day of labour. The present study reveals that only 15.7% had diagnostic lab facilities available at a walkable distance and, hence, didn't incur any additional expenditure on account of transport as against 20.9%, 59.7% & 3.7% respondents, who incurred an expenditure of <Rs 100, Rs 100-499 & Rs. 500-1000 respectively. It can be inferred, that cost affordability not only compromises the readiness of the people towards availing diagnostic lab facilities but, tend to determine the preference of the people towards private and government lab diagnostic facilities as well.

The findings of the study, further demonstrate a preference of the respondents towards the government lab diagnostic facilities over and above the respondents who preferred private lab diagnostic facilities.

Accessibility and affordability both act as cues in influencing collective health seeking behaviour of the people and are important factors for determining the acceptability.^[10] The ICMR pre-validated door step Labike was rolled under the multi-centric task force project with a purpose to examine the prospects of its scalability with a focus on availability, acceptability and affordability- the fundamental cues of health

seeking behaviour. In this regard, responses were sought from the study participants with regard to the various parameters of satisfaction.

The study revealed that majority of the respondents expressed their overwhelming satisfaction towards the Labike for various parameters of satisfaction such as accessibility to the services (98.4%), suitability of working hours (98.4%), compatibility with routine schedule (96.9%), satisfaction with the regard to the reduction in travel time due to home-based diagnostic care (98.4%), rating for privacy and transparency(98.4%), convenience of the Labike services (99.5%), quality of services received (97.4%), readiness to pay nominal charges for continuation of door step Labike services (74.3%) and overall recommendation for continuity of door step Labike services in future (99%).

With regard to further the prospects of scalability of the Labike, recommendations were sought from the study participants about the additional tests to be included in the Labike, since the broadening of the ambit of the tests, in, turn, will have an impact upon the acceptability of the Labike and its consequential scalability. Diverse recommendations were received for inclusion of more lab tests and investigations in the Labike besides, the ones already offered by this innovate diagnostic tool. The responses reflected a greater demand for investigations like Thyroid Function Test, Vitamin D test, HBA1c, Iron profile, Hepatitis serology, Hormonal assay etc. since, these lab investigations are being commonly prescribed by the health care providers, thus, reflecting the common diseases and health problems prevalent in our community.

The collective findings from the study demonstrate, that the Labike can prove to be a robust and reliable diagnostic platform. However, its successful large-scale rollout hinges

on addressing key operational and technical challenges experienced during the course of study:

1. **Supply Chain and Cost:** The current reliance on proprietary and expensive cuvettes limits cost-effectiveness and supply chain resilience. Future iterations must be redesigned to be compatible with universally available, non-proprietary reagents to ensure sustainability.
2. **Environmental and Ergonomic Design:** The diagnostic equipment's vulnerability to malfunction in extreme cold temperatures, the rapid battery drain, and the ergonomic constraint of the single-technician setup demand hardware improvements. The design requires better weather-proofing and a safer, more spacious layout to accommodate a two-person team. Besides, major modifications ought to be made in the canopy as well with regard to the material used, its durability and weatherproofing so that, it becomes heat resistant and also withstands the extreme climatic conditions.
3. **Data Linkage and Management:** The most significant systemic constraint was the intermittent or lack of reliable internet connectivity, which prevented the intended real-time data synchronization. Offline data storage and enhanced synchronization protocols are mandatory for integrating the Labike into the digital health infrastructure.
4. **Public Health Safety:** The current deficit in a functional system for bio-medical waste segregation and disposal (e.g., color-coded bins and portable sterilization) is a critical public health hazard that must be resolved through mandatory, built-in waste management protocols before further deployment.

CONCLUSION

The findings from the field beyond any doubt demonstrate that, the Labike is a powerful, well-accepted tool which can revolutionize diagnostic outreach and can, thus, significantly strengthen primary health care especially in tackling the rising burden of Non-Communicable Diseases (NCDs) in resource-limited settings. With the necessary technical and operational modifications, it holds immense potential as a sustainable model for achieving universal health coverage across vast and diverse regions.

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Conflicts of interest

There are no conflicts of interest.

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